

Bridgman Crystal Growth in Static Magnetic Fields

Frank R. Szofran/ES71

205-544-7777

E-mail: frank.szofran@msfc.nasa.gov

The objectives of this study are:

- To experimentally test the validity of the modeling predictions applicable to the magnetic damping of convective flows in conductive melts as this applies to the directional solidification and floating zone growth of solid solution semiconducting materials; and
- To assess the effectiveness of steady magnetic fields in reducing the fluid flows occurring in these materials during space processing that result from density gradients (driven by the residual steady-state acceleration or g-jitter), or surface tension gradients (Marangoni flow).

During the past year, experimental work has continued on Bridgman and floating-zone growth experiments and numerical modelling of the Bridgman experiments. Ingots of gallium-doped germanium and germanium-silicon alloys (≤ 5 percent silicon) been grown by the Bridgman method while the floating-zone experiments were done with silicon and silicon-germanium alloys (≥ 95 percent silicon). Some of these experiments were carried out jointly with colleagues from the Crystallographic Institute (KI), Freiburg University in Germany.

The immediate goal of the gallium-doped germanium experiments was to determine the magnetic field intensity necessary to achieve diffusion-controlled growth conditions. This refers to the fact that there are primarily two mass transport mechanisms taking place in the molten material ahead of the solid-liquid growth interface. These include convection driven by thermally induced density differences and diffusion of the gallium dopant within the molten germanium. At zero field, the convection is sufficiently vigorous to

completely mix the melt, that is, there is no detectable diffusion contribution to the mass transport. In a non-zero magnetic field, the convection is reduced because the liquid is highly electrically conductive. Thus, applying a high enough magnetic field should reduce the convective flow velocity to the point that diffusion is the predominant mass transport mechanism. The field at which this occurs will be dependent on the diameter of the melt and the thermal field in the melt. For the configuration which was used, both experimental evidence and numerical simulations suggest that a field of 3 Tesla is sufficient to reduce the convective transport to less than the diffusive transport. A comparison of the experimental data and a diffusion-controlled model is shown in figure 133.

The collaborative experiments with KI included silicon float zone growth and additional Bridgman growth using a KI mono-ellipsoid mirror furnace installed in a 5-Tesla magnet in the MSFC Space Sciences Laboratory. The Bridgman experiments were especially interesting in

the mirror furnace because, unlike the furnaces normally used at MSFC, the sample can be observed during growth. Fluid motions that were unexpected were observed and some expected motions were much higher in intensity than anticipated. In summary, static magnetic fields are useful to reduce convection in semiconductor melts. The three growth schemes employed, floating zone and Bridgman growth in two configurations, have been shown to be complementary. Each one provides a part of the information that will be needed to understand more thoroughly the role of gravity in the solidification of semiconductor materials. Work on doped Ge is essentially complete and attention is being intensified on the Ge-Si alloy system.

¹Rolin, T. D. and Szofran, F. R.: "Determination of the Electrical Conductivity of Liquid Ge_{0.95}Si_{0.05}." *Journal of Crystal Growth*, vol. 153, pp. 6-10, 1995.

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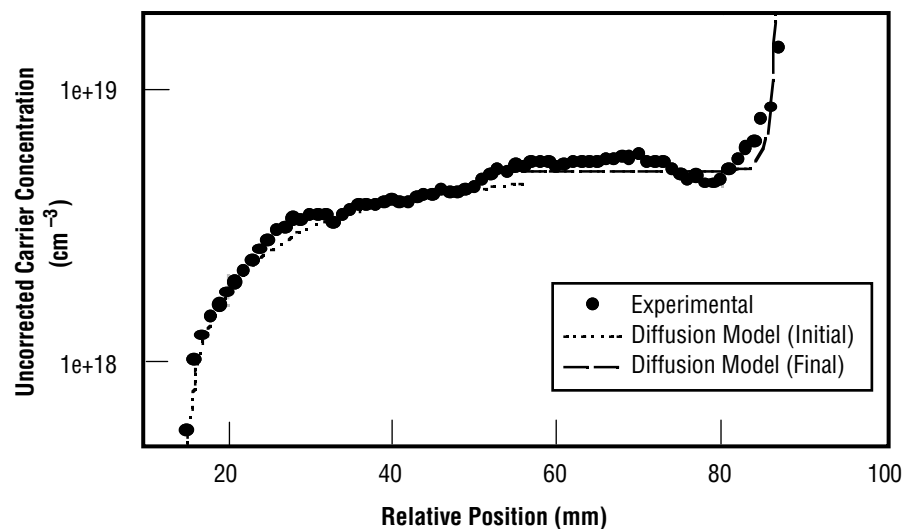


FIGURE 133.—Axial Ga distribution in a Ge:Ga sample grown at 8- μ m/sec in a 5-Tesla field.

University/Industry Involvement:

Crystallographic Institute of the University of Freiburg, Germany; Co-investigator Dr. Shariar Motakef, CAPE, Inc.

Biographical Sketch: Dr. Frank R. Szofran is a senior scientist in the Space Sciences Laboratory responsible for studying the effects of magnetic fields on semiconductor crystal growth with emphasis on the application of this method to microgravity experiments. In 1996 he spent two months at the University of Freiburg at the invitation of Prof. K.W. Benz, the director of the Crystallographic Institute. Szofran has a Ph.D. in solid state physics from Brown University (1973) and a B.S. in physics from Washington University in St. Louis, 1966. 